



ASSESSMENT OF PROPOSED SCHEDULE D CONDITIONS ON AQUACULTURE LICENCES IN THE PROVINCE OF ONTARIO

Context

Fisheries and Oceans Canada (DFO) Fisheries and Aquaculture Management requested DFO Science review the proposed new sediment licence conditions proposed by Ontario Ministry of Natural Resources for freshwater cage aquaculture operations in Ontario.

This Science Response Report results from the Science Response Process of January 2014 on the assessment of proposed schedule D conditions on aquaculture licences in the province of Ontario.

Background

In 2006, the Ontario Ministry of Natural Resources (OMNR) initiated the Coordinated Guidelines process, intended to bring under one application process the information needs of all agencies with some responsibility for cage aquaculture licencing/regulation. The management of farm waste deposits to the lakebed proved to be a highly contentious issue and the sediment portion of the Coordinated Guidelines is the last component of the Guidelines still awaiting approval.

The Collaborative Sediment Policy Development Working Group includes members from OMNR, Fisheries and Oceans Canada, Environment Canada, Ontario Ministry of the Environment, Ontario Ministry of Foods and Rural Affairs, industry, academia, NGOs and First Nations. In 2010, the Working Group agreed that the two guiding principles in the development of a sediment monitoring program for cage aquaculture would be:

- 1) that there would be no significant impairment in sediment chemistry/benthic communities from background conditions at some outer boundary distance from farms, and
- 2) that there should be evidence of waste assimilation collected between the outer boundary and the farm.

However, meeting minutes left some uncertainty with respect to the precise intentions of the Working Group. A Sediment Technical Team (STT) was tasked with developing options for a scientifically-defensible sediment monitoring program that would be included as a condition of cage aquaculture licences. The STT delivered options for monitoring to the Collaborative Sediment Policy Development Working Group to consider at a face-to-face meeting in Toronto in April 2012, and there was agreement in principle reached by all stakeholders by the end of the meeting. Government action items at the end of the meeting included the development of draft licence conditions and a draft Management Response Protocol.

Since the April 2012 meeting, the Ontario Ministry of the Environment have been developing (draft 6 dated Oct 17, 2013) "Provincial Policy Objectives and Operational Criteria for Managing Effects of Cage Aquaculture Operations on the Quality of Water and Sediment in Ontario's Public Waters", to serve as the underpinning of their current and future approaches to sediment management. This policy document identifies the STT's "Benthic Monitoring Program for Aquaculture Operations in Ontario". Accompanying the new Policy Objectives are a sediment

quality monitoring program and licence conditions that have changed from those that were accepted in principle by the Working Group.

The Ontario Ministry of Natural Resources requested DFO's input into the review of the Sediment Licence Conditions (SLC). DFO Fisheries and Aquaculture Management requested DFO Science undertake a review of the proposed new licence conditions and the required sediment monitoring program. This report evaluates how the sediment monitoring required under the proposed sediment licence conditions differs from the program supported during the collaborative process. To facilitate the comparison, the main components of the two programs are examined and compared in sequence. In cases where differences exist, the report attempts to explain what the differences are and how they may impact the outcome of the monitoring program so that regulators and stakeholders may understand the proposed changes. A section also provides some comments on proposed licence conditions without reference to the original collaborative monitoring plan.

In the following text, the monitoring program developed by the collaborative approach will be referred to as the CMP, while the sampling that would be required under the proposed sediment licence conditions will be referred to as the SLC.

Comparison of the CMP and the SLC

Objectives

CMP

The objectives of the CMP are:

- to ensure that there was no impairment of the aquatic habitat beyond the 120m operational boundary; and
- to provide proof that assimilation of waste material was occurring within the operational boundary.

SLC

The SLC objectives are:

- Ensure that "waste assimilation" (As described in Part 1 of Appendix iii of the SLC) is occurring in the Near Field Waste Footprint.
- Ensure that the aquaculture operations are not resulting in impaired sediment quality conditions in the Near Field Waste Footprint.
- Ensure that the waste footprint of the aquaculture operations does not exceed the operational boundary (as described in Part 2 of Appendix iii of the SLC).

Analysis

Although similar at first glance, the objectives are different with respect to the area within which a particular objective must be met and the operational definitions used.

There are two objectives within the CMP and three in the SLC. The SLC has added an objective that "impaired sediment quality conditions" should not be present within the Near Field Waste Footprint. There is no equivalent objective within the CMP, either in terms of the condition to be met or the restriction of a sampling area to a Near Field zone.

Both the CMP and the SLC have objectives for assimilation, although the operational definitions used for assimilation are quite different (See Evidence and Thresholds). The CMP looks for evidence of assimilation anywhere (along the three transects) within the 120m operational boundary, while the SLC looks for assimilation within the Near Field Waste footprint, a zone

which is not defined in the SLC document but from the placement of sampling sites seems to be within 40m of the cages and within the dominant ax(e)s of the waste footprint (SLC Appendix 1, Sec 2(b)).

The objectives for the operational boundary differ in that the CMP focusses on impairment of the benthic community coupled with evidence of exposure to waste (Annex A, Figure 9) while the SLC specifies that the waste footprint does not exceed this area based on chemical variables alone. This is a change from an objective of not causing measureable harm to one of no measureable exposure to waste without the requirement for evidence that the exposure is great enough to cause impact to the biological community.

In general, the objectives of the SLC represent a more restrictive set of standards and two of the three standards must be met within a much reduced area around the cages. There is a new standard that the benthic community cannot be impaired within 40m of cages, although a reduction in benthic invertebrate density is commonly observed in close proximity to cages. Without the provision of clear definitions of how the dominant ax(e)s of the waste footprint are to be determined and exactly how this will direct sample transect direction (see Locations of Test Sites for discussion), it is impossible to predict from existing data sets what proportion of existing farms will be able to meet this criterion. The SLC standard for assimilation will be more difficult to meet because of the definition of assimilation used and the requirement to do so within 40m of the cages and in the direction of dominant deposition (see Evidence and Thresholds for a more thorough discussion). The objective for the Operational Boundary is also more stringent.

Temporal Scale

Detailed timelines were associated with the CMP. Although a timeline is provided with the SLC the year of the licence cycle in which an action must occur is not always specified.

CMP

The CMP requires that the program is to be completed once every 5 year licence cycle, with sampling to occur in late September-October of the first year of the licence cycle. If the monitoring results indicate that there may be evidence that a farm has exceeded the standards for impairment or assimilation, then in year 2 sampling is conducted again to confirm the results. Failure to meet the no impairment objective at the operational boundary results in a requirement to develop and undertake mitigative actions in the second year of the licence cycle. If the assimilation criterion has not been met a second year of sampling, to confirm results is conducted before mitigation actions are required within year 3. In both cases, follow-up sampling is required in year 4 to determine if the mitigation was effective. If mitigation is not demonstrably effective then the mitigation plan is to be modified with follow-up sampling in year 5. If follow-up monitoring in year 4 suggests that mitigation actions have been successful, then sampling in year 5 is not required.

SLC

The SLC requires that the sampling program is to be conducted once every 5 year licence cycle, with initial sampling to occur in the autumn of the first year of the licence cycle. If the results of the monitoring indicate that the assimilation threshold is not met, impaired conditions exist within the Near Field Waste Footprint, or if there is evidence of exposure to waste at the operational boundary then in all cases a Supplemental Monitoring Plan including annual monitoring is triggered, with the first monitoring to coincide with implementation of the monitoring plan (Schedule X, section 6 c vi and section 6 d ii). It is not clear in which year of the licence cycle the Supplemental Monitoring plan needs to be submitted, either in the text of the document or the flowchart.

Analysis

The temporal aspects of the two programs are similar, requiring monitoring within the late autumn of the first year of the licence cycle. The choice of season is appropriate because this is the time of year when farm feed usage is typically high and because potential effects of life histories and food supply on invertebrate communities are reduced. The choice of the first year of the licence cycle is appropriate because it allows time so that if mitigative strategies are triggered, they can be implemented and their efficacy assessed prior to the start of the next licence cycle.

Failure to meet any of the objectives triggers an immediate requirement for mitigation under the SLC while the CMP treats failure to meet the no impairment criterion at the operational boundary more urgently than failure to meet the assimilation criterion. Under the CMP, the assimilation criterion was intended as an early warning and thus operators have a year to respond to the results prior to a management response being required. The delay also acknowledges the uncertainty in the assessment of assimilation. Site-specific factors can result in farm-to-farm differences in the spatial distribution of deposition and its effects on invertebrates, and the prescription of sampling site locations in both programs does as a result come with some risk that the area in which assimilation is most active will be missed. The CMP does not specify the exact location where evidence of assimilation must be demonstrated other than a requirement that it occur between the cage edge and the operational boundary and thus a second year of sampling during which farm operators may choose to adjust (or add) sampling locations to locate this zone prior to being required to undertake mitigative strategies is appropriate. The SLC looks for evidence of assimilation within 40m of the cage edges (the Near Field Waste Footprint). Sites may only be moved if benthic density does not meet the density threshold and sediment chemistry does not indicate exposure to farm waste and there appears to be no opportunity to move the sites outwards from 40m. A second year of sampling is perhaps less important with limited opportunity to relocate sites.

In cases where the operational boundary criteria are not met, the CMP allows a year for mitigative strategies to take effect before conditions are reassessed. Allowing at least one year for accumulated wastes to be assimilated and for benthic communities to recover before determining if a mitigative action has been effective is reasonable as most freshwater profundal benthic organisms are not particularly mobile over large distances in their aquatic stage and some have life cycles of a year or more in length and therefore populations cannot be expected to respond rapidly to changed deposition rates. In situations where the monitoring variable is chemical in nature, chemical and/or biological breakdown of wastes are still needed to return a site to background values. Burial and dilution (within the 2 cm slice used for analysis) by deposition of new material with lower concentration may also be required and this could be a multi-year process given the low rates of natural deposition in oligotrophic waters. The lack of scientific knowledge regarding the rate and processes of degradation of aquaculture waste on lake sediments significantly hampers our ability to predict recovery timelines and therefore what period is necessary to assess effectiveness of mitigation strategies. It may be advisable and would be more consistent if the same time delay were applied to both objectives in the CMP, however the desire of regulators to reassess and adjust actions prior to the start of a new licence cycle is also understandable. The SLC states that: "The proposed start date of the annual sediment monitoring plan should correspond with the implementation of the mitigation measures". It is not clear in which year of the licence cycle the Supplemental Monitoring plan needs to be submitted, but this text at least suggests that there is no delay between mitigation and assessment of effectiveness.

Location of Test Sites

Direction

CMP

The CMP follows what is called a radial gradient sampling design. Sampling locations are placed along 3 distance transects away from the cage arrays. The three transects are required to fall along the primary direction of water flow and then at 120° and 240° degrees, provided that this can be accomplished without placing samples in areas of hard bottom or along gradients in depth or other confounding gradients. This placement of transects and sampling sites such that they cover all directions of the waste depositional footprint allows for an assessment of shape, spatial extent and severity of the area affected within the 120m operational boundary.

SLC

The SLC also requires samples to be placed along transects but states that:

"Site specific consideration on transect and sampling station placement is required to ensure sediment samples are collected in the direction of the dominant ax(e)s of the waste footprint."

However, it is not clear how the dominant direction is to be determined (e.g., current meter data, direct observation of waste, chemical analysis), how the dominance of a particular direction is to be quantified, or exactly how this is to influence the placement of transects.

Distance

CMP

The CMP specifies sampling at distances of 10, 20, 40, 80 and 120m. The 120m site is defined as the Operational Boundary while the sites within that boundary were not provided with any particular label. At sites that experience movement of cages, the CMP specified that the distance to a sampling sites would be measured from the furthest position reached by the cages in that direction.

SLC

The SLC has two areas specified: the Operational Boundary and the Near Field Waste Footprint. The operational Boundary is at 120m from the edge of the cages. The Near Field Waste Footprint is less clearly defined. Sampling sites to assess near field conditions are specified as:

"...within 40m of the cage edges at approximately 10m, 20m, and 40 m from the edge of the cage(s) along the transects for a total of nine near field stations. Site-specific considerations may be made to ensure sediment samples are collected in the direction of the dominant ax(es) of the waste footprint."

Therefore, the waste footprint appears to be within 40m of the cage edges along the direction of maximum deposition, but the spatial extent of the footprint in other directions is not clear and would be site-specific. Also unclear is how distance is to be measured in the case where cages move. This may particularly be of concern to farms that are considering fallowing within a single licence cycle in the event that they are required to conduct separate assessment for each cage location.

Analysis

The spatial distribution of the footprint will not be assessed as accurately if sampling locations are not either randomly or semi-uniformly located around a farm because there will be little to no

sampling in some directions. The placement of all sites within the area of most concentrated deposition will result in less variability in the data but will positively bias the results (i.e., towards measuring a greater effect). This results in a higher risk of the monitoring program triggering mitigation. The more uniform placement of transects in the CMP, will negatively bias results (i.e., to a lesser effect) and will result in higher variability. Higher variability generally reduces the ability to detect effects. The collection of more replicate samples can substantially improve accuracy of estimations.

The requirement to place transects along the dominant ax(e)s of waste footprint may also fail to include the effects of sediment focussing at shore-based farms if the ax(e) directions are determined by current meter data. This is because the dominant direction of currents along lakeshores is typically parallel to the shoreline (Csanady 1972, 1984, Csanady and Scott 1974, Carter and Haras 1984, Yerubandi and Schwab 2007) while sediment focussing occurs towards the deeper middle part of the basin (Blais and Kalff 1995). The placement of transects in the CMP would result in two of the transects occurring along the dominant and subdominant deposition directions while the third transect at shore-based farms would likely be placed perpendicular to shore and therefore would accommodate focussing. We cannot predict the outcome for farms that are far enough off shore to not be affected by shoreline currents.

Failing to adjust the placement of sampling sites to accommodate natural wind-generated variability in cage location could result in sampling sites that are directly under cages for a portion of time. Movement of cages by 10m or more is not uncommon and the lack of accommodation for cage movement will significantly increase the probability of triggering a management response. Fallowing is a practice that could be used by farms to improve sediment quality conditions under and near cages, but the impact of this practice on the required location and number of sampling sites is not outlined in the SLC.

The placement of transects and sites along transects essentially results in the CMP and the SLC asking different questions. The SLC concentration of sampling sites in the direction of the main waste footprint restricts the scope of the questions regarding assimilation and impairment to the area in which waste deposition is most concentrated, thus asking:

- 1) does the maximum extent of waste deposition exceed 120m from the edge of the cages?; and
- 2) is waste assimilation occurring within 40m along the direction of maximum waste deposition?

As replicates are not required at specific distances, no inferences may be drawn other than about the general area of the waste footprint.

The CMP's uniform placement of transects and sampling sites asks the questions:

- 1) in general, at 120m from the edge of cages are there impaired sediment conditions?; and
- 2) within 120m from the edge of cages is waste assimilation occurring?

The collection of replicate sites (three at each distance) allows inferences to be drawn specifically about each distance along the transect, although not about each transect individually. This means that the question "does the operation of Farm A affect sediment 20m (or 10, 40 or 80m) away?" could be answered. The standardization of the sampling distances and collection equipment across farms further allows the question "do freshwater cage farms generally affect sediments 20m away from the cages?" to be answered. Sampling program design should be guided by the choice of questions to answer.

Location of Reference Sites

CMP

The CMP specifies that six reference locations are to be sampled and that they are to be at least 1km from the farms and approximately 500m from each other. The sites are to be "as similar as possible to the range of transect station conditions except in exposure to fish farm waste." Specifically mentioned are the need to match the range of water depth at the transect stations, to be mindful of other anthropogenic stressors and only accept sites with exposure to stressors that also occur at the farm site, and a requirement to report sediment particle size.

SLC

The SLC specifies that six reference locations are to be sampled and that they are to be 1-2km from the farms and approximately 500m from each other. The Reference sampling stations are to be comparable to the cage site stations in terms of: depth, substrate type, bathymetry, orientation, exposure, hydrological conditions and prevailing current speed and direction.

Analysis

The main differences between the two programs are that the SLC restricts reference sites to be within 2km of the farm sites while the CMP has no such restriction and that the SLC is far more prescriptive in terms of which conditions must be assessed to ensure similarity between test and reference sites. The restriction to place sites within 2km of the farm will help to ensure that no large-scale differences arising from, for example, underlying geology or shoreline land-use patterns will be included in the reference data set. Some restriction on the geographic spread of sites is advisable and probably ought to have been included within the CMP. However, experience sampling in the area where farms are most concentrated suggests that it may be quite difficult to find sites within 2km that also meet the other criteria listed and this distance should be expanded. The list of site conditions in the SLC is somewhat difficult in terms of definition and justification. What is meant by the variables, or they are to be measured is not provided. Hydrologic conditions often refer to the energetics of a site i.e., the frequency and magnitude of water movement. In lakes, these conditions are driven primarily by exposure to wind and water depth. Site exposure to wind can be measured by maximum fetch or effective fetch, a measure that combines fetch with the frequency and direction of wind. A simpler approach that can be quite effective within the process of selecting potential sites is to combine a wind rose analysis of wind data (available from local weather stations) with measures of fetch in the prevailing directions. As current speed, hydrologic conditions, exposure and orientation are all tightly interlinked it is unclear why they are all listed. The biological basis for why current direction is thought to be a necessary component of site standardization is also not clear as it is doubtful that invertebrates or substrate particles have any ability to respond to this variable. The requirement to have similar current speed and direction suggests that the industry will be required to collect current meter data from reference locations. The season and time frame over which current speed and direction measurements are to be taken is not provided and therefore the investment required to get this information cannot be properly estimated. Ultimately, wind exposure, water current speed, hydrologic conditions and even water depth largely affect lake invertebrate communities and sediments by changing sediment particle size distribution and organic content. Substrate particle size, measurement of which was required by the CMP, represents a more time-integrated measure of site energetics and can be measured from single point-in-time sampling.

To summarize, a restriction on geographic spread of reference sites by the SLC is advisable, but the restriction to within 2km is too restrictive. The list of habitat variables that require standardization between transect and reference sites by the SLC is repetitive and poorly

defined. A consideration of the mechanism through which each variable may affect monitoring program data could guide the choice of variables. An assessment of effective fetch would be useful to identify potential reference sites with an analysis of particle size conducted at each site to demonstrate that the use of fetch was successful in keeping site energetics similar.

Sampling Equipment

CMP

The CMP stipulates the use of Kajak-Binkhurst or other gravity corer and explains the rationale for doing so.

SLC

The SLC allows the use of any type of standardized equipment but specifically states that the use of a K-B corer would be acceptable.

Analysis

Within the CMP, the stipulation of the gravity corer (e.g., K-B corer) was made because this equipment is recognized in the scientific literature as providing the least biased estimates of density and community composition (aside from coring by SCUBA). Core samples are the best defined in terms of area and depth as compared with any other types of sampling equipment and give the operator the best ability to determine if the sample is of sufficient depth and is undisturbed. Gravity corers, however, are more difficult to use and are less common because their use is restricted to relatively fine-grained sediments. The PONAR, a grab commonly used in larger lakes because of its versatility, is known to have a bite profile that can be very shallow in harder sediment and thus sampling with this equipment can underestimate density. A shallow bite profile also causes underrepresentation in the community composition estimate by invertebrate taxa that inhabit deeper layers of sediments. This bias is important as the depth distribution of invertebrates within the sediments changes with proximity to the farm. In freshwater, a taxonomic group that commonly inhabits the deeper layers of sediment are the tubificinae oligochaetes (Davis 1973) which are well adapted to undertake the assimilation of farm waste. Underestimation of the abundance of these taxa might place a farm site at an increased risk of triggering mitigation to meet the SLC assimilation standard. In very soft sediments, such as would be found in the high waste depositional areas close to cages, a PONAR unless very carefully used, will sink below the sediment-water interface, which can also result in poor estimation of benthic communities.

The standardization of equipment across the program would facilitate across-farm data analysis. Data collected by corer cannot be combined with data collected by PONAR without the use of correction factors. Correction factors would have to be determined by sampling with both equipment types at the same locations. Those locations would likely have to span the range of distances from the cages to accommodate the differences in community composition and depth distribution that occur along a gradient in exposure to organic deposition. Even with site-specific correction factors determined, the use of correction factors would add increased error to the data set. Across-farm data analysis is valuable because it allows inferences to be made about the effects (or lack thereof) of an activity in general rather than restricting inference to individual study locations. Meta-analysis of monitoring program data is also very useful in situations, such as the Environmental Effect Monitoring Program for paper mills and metal mines, where an adaptive approach to monitoring is desired, with program weakness analysed and improvements made over successive monitoring cycles.

To summarize, while the program proposed by the SLC provides farmers and their consultants more freedom, it removes from the monitoring program across-site consistency in methodology.

This would reduce the ability to draw conclusions about the effects of the industry as a whole. The lack of consistency across farms would also reduce but not remove the ability of regulators to effectively assess the efficacy of the monitoring program after the first round of assessments and to make adjustments. Depending upon the equipment and the care used, density estimates and community composition information could also become less reliable. If there is no intention for the monitoring program to conduct meta-analysis of industry effects or to be adaptive over time, then the standardization of sampling device may be less important than providing choice to operators and their consultants.

Number of Samples

CMP

The CMP stipulated that at each sampling location four samples for sediment chemistry and 3 samples for invertebrates would be taken and these samples would then be combined prior to analysis. The CMP states that "these samples will be collected several meters apart to characterize an area of lake bottom several meters square." This was a compromise to improve the accuracy of benthic estimates by taking multiple samples without increasing analytical costs to the industry. Benthic invertebrates are highly spatially variable; this is well known in the scientific literature. Therefore, the reliability of estimates is improved substantially by the collection of >1 sample. Pooling the samples before analysis recognized that the scale of variance for the assessment was among-stations not within-station.

SLC

The SLC specify that a single sample is to be taken at each location unless a K-B corer is used, in which case 4 samples for sediment chemistry and 3 samples for invertebrates would be taken and composited prior to analysis. There is no specification as to the spacing of the samples within a sampling site.

Analysis

Under the proposed SLC, if a farm operator chooses to use the K-B corer, then there is no difference between the programs. If a different piece of equipment is used and as a result single samples are taken at each sampling location, there are potential consequences. Essentially this comes down to the use of a single sample or multiple samples to characterize conditions at a single location. Although benthic grabs sample a larger surface area as compared to a K-B corer, benthos are well known to exhibit a contagious (patchy) distribution (Elliot 1977, Downing 1979, Allan 1984) and thus the use of the mean of multiple samples collected over an area of several meters square to characterize the benthos versus a single sample probably provides a more accurate estimate. Chemical variables in sediment are less likely to have patchy distributions and thus multiple samples may not provide much advantage. The extrusion of a core versus scooping the top off a grab sample does, however, provide better control over the depth of sediment removed and the ability of the operator to ensure that an undisturbed sediment-water interface has been collected. Both will theoretically result in more accurate measures resulting from core samples, but this difference has not been quantified.

Analytical Variables

At the Operational Boundary

CMP

The CMP asked farmers to assess both benthic invertebrate communities and sediments at the 120m station. The CMP requires the measure of benthic invertebrate community composition at the resolution of Family for most groups, sediment chemical composition (total organic content,

LOI, sediment particle size, total phosphorus, total nitrogen and a multi-element ICP scan that included Ca, Cu, Zn, Li). Water depth, oxygen concentration 1m above the sediment and observations of sediment texture and smell and the presence of faecal material, waste feed, bacterial mats or gas bubbles is required.

SLC

The SLC asks only for sediment chemistry. This includes total organic content, total phosphorus, total Kjeldahl nitrogen, Cu and Zn. The recording of water depth and observations of sediment texture and smell at each site and the presence of faecal material, waste feed, bacterial mats or gas bubbles is required.

Analysis

Reliable chemical surrogate measures of benthic conditions are often sought for use in monitoring programs as a means of substantially reducing costs. As discussed in the CMP, the relationship between sediment chemical variables and benthic invertebrate communities is significant, but the strongest relationship thus far developed, between sediment total nitrogen and benthic invertebrate abundance, still accounted for less than 40% of variability. If the objective at the operational boundary is to ensure that impaired conditions do not exist then the direct measure of invertebrates is the most accurate means of doing so.

The questions asked by the CMP and the SLC differ and this affects which variables need to be measured. The SLC's third objective regarding the operational boundary is that the waste footprint of the aquaculture operations does not extend past this boundary, whereas the CMP's objective was to determine if impaired conditions existed at this boundary. Chemical variables are certainly all that is required to determine if sediments at the operational boundary are being exposed to waste material. The choice of analytical variables should be guided by a consideration of the desired environmental objectives.

Within the Operational Boundary

CMP

The CMP requires the measure of benthic invertebrate community composition at the resolution of Family for most groups, sediment chemical composition (total organic content, LOI, sediment particle size, total phosphorus, total nitrogen and a multi-element ICP scan that included Ca, Cu, Zn, Li). Water depth, oxygen concentration 1m above the sediment and observations of sediment texture and smell and the presence of faecal material, waste feed, bacterial mats or gas bubbles is required.

SLC

The SLC requires the measure of benthic invertebrate abundance and community composition at the resolution of Family for most groups and sediment chemical composition (total organic content, total phosphorus, total Kjeldahl nitrogen, Cu and Zn). Water depth and observations of sediment texture and smell and the presence of faecal material, waste feed, bacterial mats or gas bubbles is required for each site. The measurement of any additional variables are left to the discretion of the farmer.

Analysis

The primary difference between the programs is the additional suite of chemical variables requested by the CMP and the measurement of sediment particle size. The additional variables were to be used in the CMP in the event that results suggested that objectives were not being met by allowing a more detailed review of the likelihood that effects were the result of farm activities versus some other environmental gradient.

Evidence and Thresholds

At the Operational Boundary

CMP

The evidence used by the CMP to determine that impaired conditions are present is outlined in Table 3 of the CMP. Impairment of the benthos is indicated by a 4SD reduction from reference site conditions accompanied by proof of exposure to farm waste as measured by chemical variables exceeding $\text{ref} + 2\text{SD}$. The flowchart provided with the CMP does not agree with Table 3 in that it uses a criterion of $\text{ref mean} + 4\text{SD}$ for chemical variables (total organic content, LOI, total phosphorus, total nitrogen Ca, Cu, Zn); however, the flowchart exists only as a draft document and therefore this is assumed to be a typographical error. The flowchart outlines a process in which a single chemical measure higher than $\text{ref mean} + 2\text{SD}$ would trigger an assessment of the supporting sediment variables and site data along all transects to determine if there was weight of evidence to support that the high values were likely a result of farm effect.

In the CMP biological thresholds concerned three aspects of community composition: density, richness and the Bray Curtis index, which is a measure of how similar the community structure at test location is to that observed at reference locations. Impairment of the benthic community is indicated by a reduction of at least 4SD from reference conditions.

SLC

The SLC use the value of chemical variables with the reference mean plus 2SD as the threshold above which exposure to farm waste is deemed to be occurring at the operational boundary. According to Appendix III, Part 2 ii. of the SLC, a single sample in which any one of the chemical variables exceeds the value of the reference mean plus 2SD results in the determination that the waste footprint exceeds the operational boundary.

Analysis

The thresholds for the SLC are more stringent than the CMP because a management response is triggered by evidence of exposure not impairment and because a single chemical measure is enough to trigger versus the use of a weight of evidence approach utilizing multiple chemical measures and multiple transects. Exposure to farm waste does not necessarily result in impaired benthic conditions as measured by altered states of the benthic community. This difference can be related to differing objectives for the operational boundary between the CMP and the SLC. The use of multiple chemical measures and a weight of evidence approach recognize that a single chemical variable can be elevated at a site for reasons that are unrelated to aquaculture. The use of a suite of variables representing the characteristic signature of farm waste provides a higher level of confidence that farm activities are to blame and that a requirement to undertake mitigative actions is warranted.

The effect size for changes in density that trigger a management action are different; the CMP uses a reduction of 4SD from reference, while the SLC uses 2SD. The use of 4SD is roughly equivalent to the use of 99.9% prediction limits and the use of prediction limits was deemed appropriate because the density at individual sampling sites is being used to compared to reference sites. The use of 4SD is also similar to the criteria for change from reference condition that are used in the BEAST benthic monitoring program for the Laurentian Great Lakes. Reynoldson et al (1997, 1998) recognized the following categories of difference from reference sites:

1. within a 90% confidence ellipse of reference: equivalent to reference
2. between 90 and 99%: possibly different

3. between 99 and 99.9%: Different or possibly stressed
4. outside of the 99.90%: very different or impaired.

For $n=6$, the critical t values (one tailed) representing 90, 99 and 99.9% are: 1.476, 3.365, and 5.893, so the use of 4SD lies somewhere between 99% and 99.9%.

In data sets with high variability it is possible that 4SD below reference mean could include zero, and it is difficult to accept that an absence of invertebrates could be considered to be within reference conditions. The solution to this is not to use a smaller effect size, because the sampling program does not have the power to reliably detect such a small effect size. The CMP was calculated as capable of detecting a 4SD deviation from reference with a 10% probability of falsely concluding impact and a 80-90% chance of detecting an impact if present (pg 27 and Appendix E of the CMP). The change to a smaller effect of 2SD was calculated to be detectable less than 50% of the time and this calculation would also apply to the SLC. A better solution to the problem is to improve the estimate of density and the variance of this estimate at reference sites such that 4SD does not include zero. This can be accomplished through sampling of a higher number of reference sites, the collection of more samples at each reference site, and the use of measures to ensure that reference sites are very well standardized with respect to habitat conditions. The costs to process additional reference site samples can be minimized by processing only enough samples to attain acceptable estimates.

There is a curious disagreement within the SLC regarding how the operational boundary data will be interpreted. Appendix III states that the waste footprint will be assessed as exceeding the operational boundary if any one of the chemical variables exceeds reference plus 2SD:

"Part 2. Operational Boundary Assessment"

Waste Footprint Does Not Exceed the Operational Boundary: *total organic carbon (TOC), total phosphorus (TP), total Kjeldahl nitrogen (TKN), copper (Cu) and zinc (Zn) concentrations are all equal to or less than plus two standard deviations of the Mean of the Reference Sampling Stations for all Operational Boundary Sampling Stations*

Waste Footprint Exceeds the Operational Boundary: *any of TOC, TP TKN, Cu or Zn concentration is greater than plus two standard deviations of the Mean of the Reference Sampling Stations for any Operational Boundary Sampling Station."*

However, Appendix 1 of the SLC states the following:

"An Operational Boundary Sampling Station is considered to be inappropriately sited and within the waste footprint if the sediment chemistry results for that station indicate that any of TOC, TP TKN, Cu or Zn concentration is greater than plus two standard deviations of the mean of the Reference Sampling Stations."

As a result, any sites that would result in the farm failing the operational boundary assessment are technically deemed to be inappropriately located and as a result would not be used in the assessment of the data as per Appendix 1 section 3 c:

"In the case that a Near Field or Operational Boundary Sampling Station(s) has been determined to inappropriately sited, the data for that station(s) shall not be included in this or any subsequent Near Field or Operational Boundary Objectives Assessment."

If multiple sites fail the assessment criteria and are therefore deemed to be inappropriately located, they would have to be moved and resampled. This creates a situation in which it is theoretically impossible for a farm to fail the operational boundary assessment. The farmer or their consultant would have to keep moving sampling sites until the new site(s) passed the threshold criteria. It is assumed that this is an error in the intent of the conditions.

Within the Operational Boundary

There are two lines of evidence to be considered. The first is evidence of assimilation. The second is evidence that impaired benthic conditions are present within the near field Waste Footprint; this criterion applies only to the SLC.

CMP

The CMP looks for evidence of assimilation anywhere within the 120m operational boundary. Observation of the characteristic Pearson-Rosenberg response curve is used as evidence of assimilation and there is no formal threshold associated with this other than the observation of the response curve.

SLC

The SLC also uses an increase in invertebrate density as evidence that assimilation is occurring. However, it uses a minimum threshold density of at least 2SD above the reference mean and couples this with a requirement that this elevated density is observed at a minimum of 50% of sites within 40m of the cage edges. Existing data indicates that 2SD increase above reference requires more than doubling of invertebrate density.

Analysis

While both programs seek evidence of assimilation, the approach to detecting it is quite different. The SLC attempts to directly use a density of invertebrates as a surrogate measure of assimilation, while the CMP uses a more qualitative approach. There is good evidence from the marine environment, starting with Pearson and Rosenberg (1978) that there is a characteristic response of benthic communities that occurs along a gradient in organic enrichment. The model describes an increase in the density and reduction in diversity of invertebrates that occurs at moderate levels of organic enrichment and results from the change in the benthos from an unimpacted community to one dominated by high numbers of animals that are adapted to the use this material as a food source. This response was depicted in Figure 3 of the CMP. The qualitative observation of this response is used by the CMP as an indication that a community that is suited to assimilate organic material is present. However, the model does not quantify the degree of increase in density. A specific density of animals present in sediments does not in itself provide any guarantee of a particular rate of assimilation of waste because size and feeding ecology of invertebrates will significantly affect this rate, and because there are many processes through which organic material is degraded or assimilated in freshwater environments.

It is not clear if the Collaborative Sediment Working Group desired the preservation of the process of assimilation into invertebrate tissue or more generally the preservation of the recovery potential of sediments. The recovery of sediment from the deposition of organic waste to a state that resembles original or non-impacted conditions includes both assimilative and nonassimilative decomposition processes. The decomposition of organic material in the freshwater environment is a complex process that includes chemical and biological degradation of the material and results in the mineralization and assimilation of the material. Mineralization is the return of material through a series of biological and chemical steps to an inorganic form. Assimilation is specifically the conversion of nonliving material to living biomass through the process of consumption/absorption and growth of tissue. Assimilation can result in the production of invertebrate, fish, microbial or fungal biomass. Assimilation of waste material into invertebrate tissue will occur any density of invertebrates (except zero) and assimilation into biomass of other trophic groups can occur in the complete absence of any invertebrates. For example, assimilation of aquaculture waste into wild fish tissue can occur indirectly through consumption of invertebrates or by direct consumption of waste material by fish. Investigation of

the decomposition and assimilation of aquaculture waste in freshwater ecosystems is largely absent in the scientific literature and as a result the criteria to assess this ecosystem function are not developed or widely accepted by the scientific community.

Benthic invertebrates are used in monitoring programs because they have a number of characteristics that result in community composition reflecting environmental conditions and because they are an essential link in energy flow to higher level consumers such as fish. Many benthic invertebrates are consumers of organic detritus and therefore would be partially responsible for the decomposition and assimilation of aquaculture waste. Invertebrates also play an important role in influencing within-sediment processes such as flux of oxygen and nutrients, and therefore the density and community composition of invertebrates will influence decomposition rates. However it is difficult to identify any evidence in the scientific literature that would support the use of a reference plus 2SD threshold for invertebrate density or any other specific density as evidence that assimilation of waste material is occurring.

There are lines of reasoning that suggest that the use of a specific density, such as a threshold of 2SD above reference density, is not scientifically supportable as a surrogate measure of assimilation capacity. Assimilation by invertebrates relies first upon the process of consumption of the material by those animals and in general consumption is a function of biomass not of density. Consumption rates by freshwater invertebrates are not well studied, but Cummins & Klug (1979) and Thonmann et al (1992) reported consumption rates approximating 30% of body weight per day. The individual biomass of organisms changes along a deposition gradient (DFO, unpublished). Figure 1 shows quite clearly that the individual biomass of organisms in areas receiving approximately 3 or more mg C m⁻²day⁻¹ can average as much as 5 times that of organisms in areas receiving background deposition rates. With consumption rate a function of biomass, a density of these larger individuals that is far less than that in reference locations would be capable of producing a similar assimilation rate. An increase of at least 2SD is equivalent to more than doubling the reference density of invertebrates and the need to replace organisms on a one to one, or in fact a 2 for one ratio to assure assimilation of waste material is hard to justify when these organisms could be consuming five times the amount of material on an individual basis. Furthermore, at sites exposed to waste deposition, a greater proportion of the individuals in the community will be deposit feeders.

The CMP looks for assimilation anywhere within the Operational Boundary while the SLC looks for assimilation only in an area restricted to within 40m of the edge of the cages and only in the direction of main deposition. This spatial restriction will make it harder for farms to meet the assimilation criterion. In 2012 DFO collected samples from a farm in Lake Huron following the CMP protocols (Figure 2). Of the 9 samples that were collected within 40m of the cage edges, four failed to show density that was at least 2SD higher than reference density. This is although all three transects clearly show evidence of the Pearson-Rosenberg response curve. Figure 3 shows some of the sediment chemistry data along those transects and the data suggest that transect three would likely not have been along the direction of main waste deposition and as a result could have been excluded by the SLC. Fifty percent of the remaining six samples would have met the SLC assimilation threshold of 2SD above reference density.

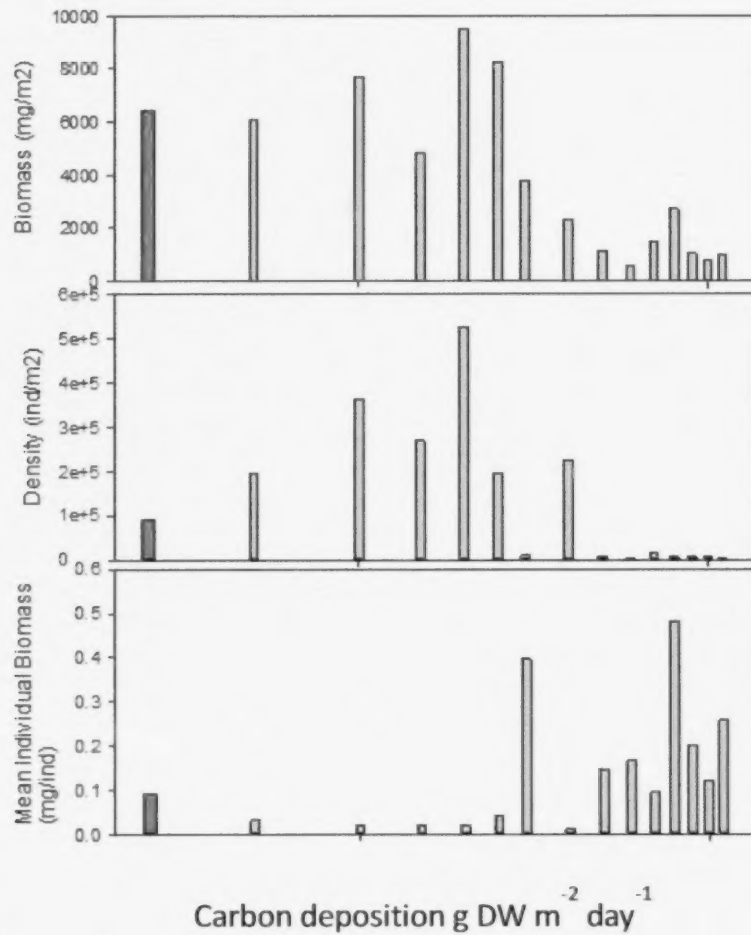


Figure 1. Density, total and individual biomass of invertebrates along a carbon deposition gradient at a farm in Lake Huron

Farm 3, 2013

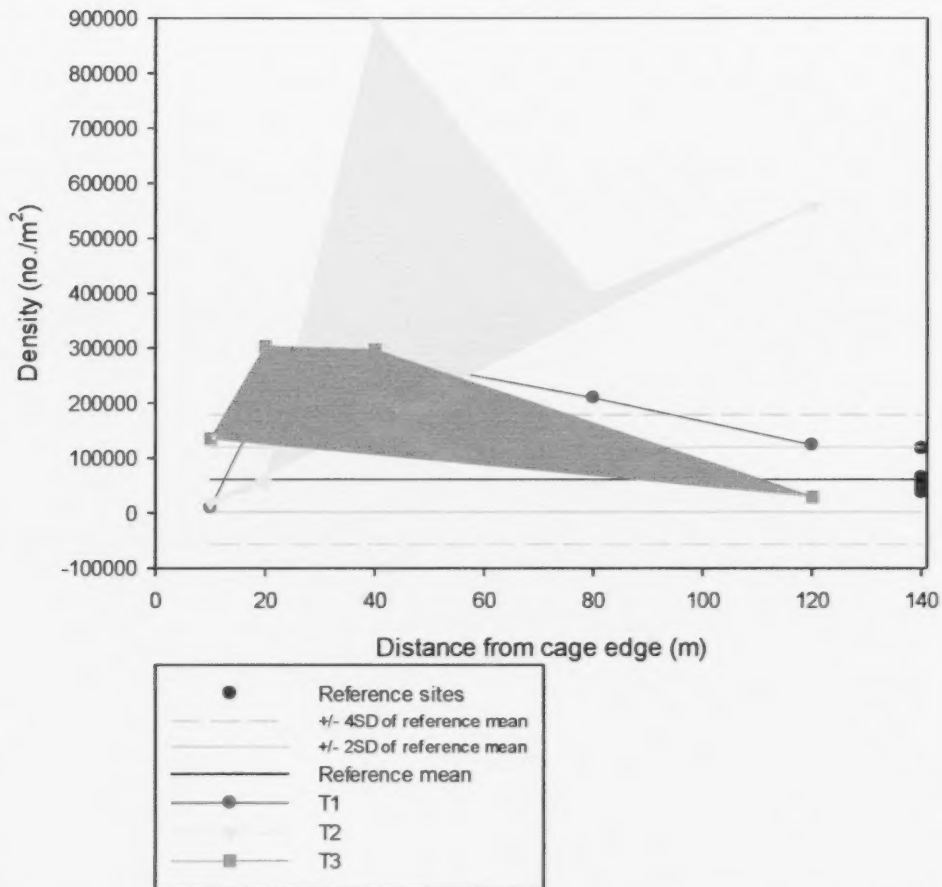


Figure 2. Density of invertebrates along 3 sampling transects at a farm and at 6 reference locations in Lake Huron. Blue symbols placed at 140m indicate the values at reference locations that were all at least 1km distant from the farm site. The mean value and 2SD and 4SD deviations from the mean are indicated by horizontal lines.

Lake Huron 2012 - Farm 3

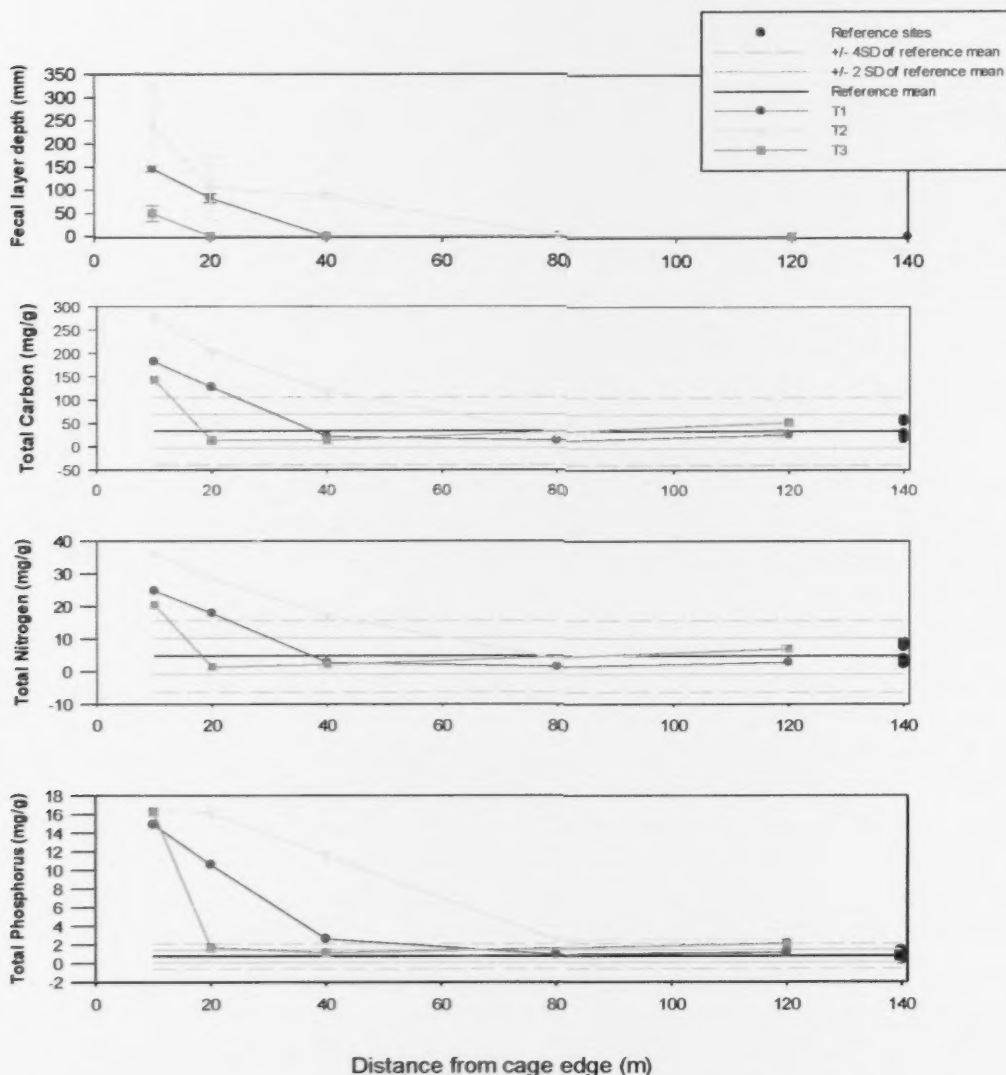


Figure 3. Depth of faecal accumulation and sediment concentrations of total phosphorus, nitrogen and carbon along three sampling transect at Farm 3 in Lake Huron. Blue symbols placed at 140m indicate the values at reference locations that were all at least 1km distant from the farm site and the solid and dotted horizontal lines indicate the value of the reference mean plus and minus 2SD and 4SD, respectively.

DFO Science has some information on benthic conditions at seven of nine farms currently operating in Ontario and with the exception of one farm, all have a zone under and near to the edge of the cages within which invertebrate density and diversity is reduced. By restricting sampling for a criterion of significantly elevated density within approximately 40 m of the cage edges, the chances of locating sites in the area in which invertebrate density is reduced will be much higher, leading to an increased risk of triggering additional monitoring based on the use of

a threshold that is not strongly linked to assimilation rate. Almost every farm that has been sampled by DFO shows an area of increased density of invertebrates between the cages and 120m.

The questions to be considered here are:

- 1) what form of evidence of assimilation is defensible given that this area of science is currently poorly developed; and
- 2) should this evidence be required to be measureable within 40m of the cages edges (SLC) or within the operational boundary (CMP).

The latter question is a decision between different environmental management objectives.

The SLC have an additional objective that is not part of the CMP and that is to ensure that the aquaculture operations are not resulting in impaired sediment quality conditions in the Near Field Waste Footprint. In this context, impaired conditions are indicated when more than half of the sampling stations have a density that is lower than the minimum reference density. There are no statistical characteristics to that statement: i.e., the Conditions do not state that density is a particular quantity lower or that they are significantly lower. The Conditions state that the density threshold is "the minimum (lowest) reference density", suggesting that any amount lower (e.g. a single individual per m²) than the lowest reference density observed would be considered to be in an impaired condition. This condition is tied to the new Policy Objectives, but within the Policy Objective the scientific rationale for the use of this threshold is not discussed. Given that density measures in a survey such as the SLC are estimates of means that therefore include some uncertainty and that only a single sample is required at each site, some adjustment of this criterion may be advisable to improve its defensibility.

General Comments

The SLC would benefit from further clarification, additional editing and use of plain language. A glossary of terms used should be provided so that all readers have a common understanding of what is meant by the terms. This is particularly important given the diversity of backgrounds of the various stakeholders.

Further guidance should be provided to allow farmers or their consultants to better understand and meet some requirements, such as those to ensure that transects are placed in the direction of the dominant axis of waste deposition or how similar habitat variable such as current speed must be between reference and test sites to be acceptable. This would also assist in ensuring consistency in the application of these requirements over time.

The requirement for farms to disclose all modelling data is not reasonable when the monitoring program does not require any modelling. If it is felt that modelling of deposition is vital to the locating of sampling locations, and requiring that this information be disclosed certainly suggest its importance, then a requirement to conduct modelling needs to be a part of either of site applications or the ongoing monitoring program.

Conclusions

The two programs differ fundamentally with respect to the questions that are being asked by the experimental design and in the definitions of thresholds. Our main observations are:

- The placement of sampling sites in the SLC restricts the scope of conclusions that can be drawn from the program to the direction(s) of main waste deposition. The lack of standardization of sampling distances may further restrict the ability of the program to analyze data across farms.

- Sampling focussed in the direction of main deposition may bias the results upwards, thus increasing the probability of exceeding the objectives compared to uniform or random sampling around a cage site.
- There is no provision in the SLC to adjust the placement of sampling sites to accommodate the natural movement of cages due to wind and waves. This could result in the placement of sampling sites that are directly under cages at times, increasing the likelihood of exceeding management objectives. How operational practices such as deliberate relocation of cages to reduce the impact of deposition (fallowing) may affect the placement or number of required sampling sites is not defined.
- The SLC restrictions on the placement of reference sites will reduce the influence of any underlying geology or other large scale habitat differences; however, the mechanism through which some of the habitat variables could affect the monitoring data is unclear.
- While the SLC allows more freedom in the choice of sampling equipment used and requires the collection of fewer samples, this could affect the accuracy of invertebrate community composition data and result in a lack of data consistency within the program. This presents challenges for data analysis across farms, between years, etc.
- The SLC looks for evidence of waste exposure at the operational boundary rather than a level of impact that could cause biological impairment. In the SLC, a single sampling result can trigger a management response. A more holistic weight of evidence approach could be considered.
- The SLC uses a smaller effect threshold (2SD) than the CMP (4SD) for comparison of invertebrate density to reference sites. Neither program has the power to reliably detect a 2SD effect size and the use of 4SD is more consistent with other benthic assessment criteria. However, some data suggests that this interval can include a zero which presents challenges for acceptability. Additional sampling at reference sites and careful choice of sites could be used to reduce the size of the 4SD interval so that does not include zero.
- The SLC Operational Boundary Sampling Station acceptability criterion, as written, states that the station is inappropriately located if the sediment chemistry results exceed the threshold. This technically removes the possibility of a farm triggering a management response.
- The SLC and the CMP use different definitions of assimilation. The SLC criteria for determining that assimilation is present has less support scientifically than the evidence required by the CMP. Assimilation is more directly a function of the biomass of organisms than density and there are data supporting the conclusion that the SLC threshold could trigger a response prematurely.
- The SLC looks for evidence of assimilation within a distance of 40m from the edge of the cages. The CMP looks for assimilation anywhere in the operational boundary.
- Mitigative actions are triggered immediately for both near field and operational boundary objectives under the SLC while the CMP requires immediate action only for a trigger at the operational boundary. Given uncertainty regarding the time required for assimilation to be detectable, provisions for additional sampling could be considered.
- SLC has added a new condition that impaired sediment quality (i.e., 50% or more of the near-field stations fail to meet the density threshold of the minimum reference station density) may not be present within 40m of the cage in the dominant direction(s) of waste deposition.

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